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Management of Technology in Centrally Planned Economy

Jong-Tsong Chiang

February 1990 WP 3130-90-BPS

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Management of Technology in Centrally Planned Economy

Abstract

This paper studies the management of technology in centrally planned economies, namely, the USSR and East European countries. From a cross-technology perspective, technologies under investigation mainly cover military, nuclear power and computers with a view to contrasting their distinctions. To further support the arguments made, technologies like space, laser, automation, new biotechnology and new materials are also mentioned where appropriate. In addition to the cases in different national contexts, the international cooperation within the framework of the CMEA (or COMECON: the Council for Mutual Economic Assistance) is discussed. To depict the patterns of management of technology in the East as opposed to that in the West, only systematically determined issues are the main foci in this paper. The preliminary conclusions reached are:

1. Relative to the West (and, in military field, mainly the U.S.), the East (mainly the USSR) has performed well in military and space system technologies, and in nuclear power technology but at the great expense of safety terms. In computer technology and several others like laser, robotics, new materials and new biotechnology, the overall records of the East are quite poor.

2. The Eastern strikingly uneven performance in various technologies of strategic importance suggests the existence of some systemic patterns of "interactions" between national institutions and technologies of different characters.

3. With respect to the dynamic nature of technology, a centrally planned system tends to perform relatively poorly when technology progress manifests "paradigm change" which requires autonomous and entrepreneurial initiatives to capitalize on the opportunities. But with typically strong, centralized leadership and long-term commitment, this system may work satisfactorily in technologies that are in "trajectory" phase.

4. Limited to military technology, a centralized, command system in a follower position tends to perform better in system technology than in basic technology, because the latter needs more freedom and autonomy to prosper, and the former mainly applies rational calculation in integrating "element technologies" mostly "on the shelf" or in "trajectory" phase. Should major innovations arise at the "element technology" level on the competitors' side, the time lag before they are incorporated into the system may give a command system a chance to make up for its possible weakness in system technology.

5. The technological "dual structure" consisting of a strong military sector and a weak civilian sector tends to inhibit "spin-off" and "spin-on" effects, nullify "virtuous circle" between military and civilian technologies, and underutilize "dual use" technologies.

6. The "doubly" centrally planned system at the national and international levels tends to seriously suffocate joint technological initiatives across national boundaries. In the meantime, lack of market mechanisms will retard economically motivated technology transfer and joint R&D.

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1. Introduction

When the relevant information was being collected and field study done, Eastern Europe and the USSR were undergoing drastic transitions. For an analysis of current state, terms like "the East," "Soviet-type," "Soviet bloc" or "centrally planned economy," and organizations like the Council for Mutual Economic Assistance (CMEA) are all questionable now given the present prevailing structural reforms and centrifugal forces within the East bloc. This paper, however, is mainly to study the crucial managerial issues in technology development in "classic" centrally planned economies with at least moderately industrialized level. Hence many facts under investigation have long been existing. Besides, the changes in the East bloc so far are mostly confined to political and economic arena. General phenomena in science and technology (S&T) activities have not been deviated very much from the past track. Therefore most of the arguments are supposed to hold for the present situation.

With a view to comparing the patterns of management of technology (not management of science) between the East and the West, this paper will focus on systematically determined issues relating to the centrally planned system. Though policy decisions, economic situations, development stage, historical loci and many other aspects specific to individual programs and countries cannot be overlooked, only those which can rather reasonably be attributed to systemic character will be discussed. Because of the difficult access to reliable information[1] and the language barrier encountered in the research process,[2] many reports with English language translation and personal field visit observation and impression without rigorous data support have to be relied on. It is hoped that these limitations would not seriously hamper the objective in this research to grasp the main threads for a brief "pattern analysis."

2. Science and Technology Development System and Innovation

2.1. "Dual" and Compartmentalized Structure

The pivotal role of S&T in socio-economic development is recognized in classic communism. Ever since the Bolsheviks set out to industrialize the USSR, S&T has been on the party-state central agenda. Despite the policy fluctuation in the early decades between high self-dependence and more interaction with the West, the strong mobilization of R&D resources and nationwide institutionalized S&T activities characterize the Soviet S&T tradition.[3]

After World War Two, the S&T system in the USSR was also modeled by or, as many have argued, imposed upon Eastern Europe after the USSR dominated this area. To some extent, Communist China adopted a system of similar character. But the case of China involves deep "South" (as opposed to "North") features in addition to "East" (as opposed to "West") ones[4] which are the foci of this paper. It is thus not to be discussed except in rather self-evident occasions needing no special elaboration.

The approach of "Soviet-type" S&T system is to centralize R&D activities to avoid the flaws of Western pattern (e.g., inefficiency due to competition and duplication among secretive independent firms and frequent lack of adequate financial support from government), and to insulate them from the "noise" of daily production and profit-making so as to concentrate on "really important" topics. This system, by simplicity, can be regarded as consisting of three levels and, at the second and third levels, three major subsystems.[5]

At the top level is some kind of commission planning and coordinating S&T activities on a nationwide basis. However, the defense S&T subcommission or some responsible authorities have normally exerted much more influence over military S&T development than the non-military counterparts have done over non-military matters. Moreover, the influential military, which resulted in part from a continuous and pervading sense of military threat from the West, has also biased resource allocation at the expense of non-military sector. Therefore, S&T development having immediate or potential military applications is far better supported, coordinated and monitored. This is in contrast with what happens in a typical market economy where the military, a major force applying state planning and control, is confined to areas of apparent military

relevance. The civilian sector, endorsed with relatively more resources and prompted by commercial motives, possesses rather strong technological capabilities. As a result, the relative technological strength in military and non-military sectors in a typical centrally planned economy is in reality far more "unbalanced" than that in an advanced market economy.

At the second level--the ministerial level, there are three "pyramids": the academy of sciences responsible for basic and fundamental research, the industrial ministries for applied R&D relating to their industries, and the ministry of education (mainly department for higher education) for education related research.

The third level consists of many frontline R&D and technical institutes and labs that carry out specific projects. Because these institutes and labs are normally responsible vertically to their respective ministries or academy, the horizontal and lateral communication and personnel mobility are seriously hampered. Without strong initiatives empowered by the top level authorities to concert highly prioritized R&D across the organizational boundaries, active exchange and cooperation between these three "worlds" are scanty. There is little market force as a major impetus to mobility of R&D human resources, exchange and transaction of technical information, investment in risky but potentially profitable innovations, and commercialization of new products and processes.

2.2. Systemic Barriers to Innovation

Without taking into account the adverse effects of Western embargo mainly through the framework of the Coordinating Committee for Export to Communist Area (COCOM), the Soviet-type S&T development system has in general a number of systemic barriers, albeit to varying degrees in different countries, hindering especially the non-military technological innovation.

First, unlike in Western countries where many firms execute concurrently military and civilian R&D and production (though with rules to restrict the diffusion of classified information), these two missions in the East are normally implemented by different formal organizations, and military related departments are strictly insulated

from non-military departments. Besides, far too much scientific research is classified on the basis of its stated military importance and is immune to criticism.[6] This results in very little technology diffusion from military sector to civilian sector.

Second, because of the compartmentalization of three "pyramids," universities suffer from lack of high calibre researchers as teachers and of challenge from advanced research projects; labs in the academy of sciences which are traditionally strong in theoretical research and at the "blackboard end" are weak in getting through to the application phase; and technical units under industrial ministries are working at best only on short-term trouble-shooting and incremental improvements without steady infusion of more innovative ideas from scientific community.[7]

Third, the separation of major R&D organizations from production and market in effect impedes R&D units' contact with potential users of their R&D results, and deprives them of better and quick understanding of and response to the real world demands. This weakness can hardly be overcome by the effort made by the state planning and coordination bodies, because they are normally distant from and thus poorly informed of the real world practices.[8]

Fourth, the non-profit character of R&D activities suppresses the economic incentives of both organizations and individuals, which may otherwise encourage commercialization of R&D results or technical services to industries. This character also frees many R&D projects to aim at world advanced targets regardless of local reality, and the achievements, if any, are very often difficult to apply in the industry.[9]

Fifth, the system of financing institutes rather than projects helps create and strengthen a tendency of budget allocation according to the size of R&D organizations. This tends to reduce performance competition, encourage size-expansion and internal promotion based on seniority rather than merit, and demotivate devoted and talented staff.[10]

Sixth, the best educated new comers normally seek R&D jobs, or are assigned to R&D institutes to ensure the quality and standard of the research work. As a consequence, outstanding scientists and

engineers tend to cluster in some prestigious R&D institutes, and a great capability gulf between R&D and production units thus persists.[11]

Seventh, the industry, due to the lack of relatively strong technical staff and close linkages with advanced R&D institutes, is usually technically obsolescent. It is also unable to provide proper facilities and services needed in advanced R&D projects, thus seriously impeding many advanced S&T programs.[12]

Eighth, a combination of the lack of market competition pressure and the common quantitative output goals requested by the state leads to a strong conservative and even negative attitude toward innovation in the industry.

Ninth, the weak innovative incentives and capabilities of the production sector further stymies the exploitation of technology imported from the West. Therefore the cost of technology imports may very often be more than the benefit, leading to the deteriorating balance of payments.[13] The fact that there is a widening gap of most industrial products' technical content between the East and the West for the past two decades[14] seems to indirectly support this concern.

Finally, the political and bureaucratic rigidity, delays, interference and misconceptions not only suffocate many autonomous initiatives, but also demoralize working level research staff. To pursue the scientific enquiry of interest to themselves, many scientists regularly exploit the ignorance of policy-makers and the indulgence of program administrators to their advantage. As a result, many S&T activities are actually much deviated from the original plans or unlikely to yield any real value to national interests.[15]

What has been mentioned above is not intended to be inclusive. It is just a qualitative description of the general and "regular" phenomena with many "exceptions" discounted. Nevertheless it is quite evident that most problems are interrelated and even self-reinforcing. Based on this rough knowledge about the whole picture, many issues in the management of more specific technologies as will be discussed below would be more understandable. To contrast the possible distinctions, three

strategically important technologies--military, nuclear power and computers--are mainly chosen for in-depth comparison, along with a brief elaboration of space technology, laser, robotics, new biotechnology and new materials to supplement the mainstream analysis of the three fields.

3. Military Technology

3.1. Comparison of Military System and Basic Technologies

Without question, the Soviet hegemonistic position in the world is mainly based on its superior military muscle rather than economic strength. Besides, it dominates the Eastern military technology because the advanced weapon systems in the Warsaw Pact are mostly of Soviet development and even production.

The Soviet military technology, in striking contrast with its civilian technology, has been a remarkable success story. Two decades after three devastating crises--the First World War, revolution and civil war, the fledgling Soviet industries and laboratories matched what Germany could produce in the Second World War. Again about two decades later the USSR held their own against the technological might of the U.S. All this feat has been achieved with an industrial and technological base always smaller and less advanced than its competitors'.

In military technology, the U.S. Department of Defense (DoD) recently has made a comparison between the U.S. and the USSR, irrespective of how achieved.[16] Among the 20 aggregate basic technologies which are thought to have the greatest potential for improving military capabilities in the next 10 to 20 years and are "on the shelf" available for applications, the U.S. leads the USSR by a significant margin in most categories, including computers and software, sensors, guidance, optics, advanced structural materials, microelectronics materials and integrated circuits, automated manufacturing, signal processing, telecommunications and life sciences. But the USSR is roughly on a par with the U.S. in the more "traditional" items, such as aerodynamics, conventional and nuclear warhead, power sources and directed energy (laser). However, in

most fields where the U.S. is ahead of the USSR, the U.S. position is being eclipsed. Only in computers and software, the U.S. lead is believed to be widening.

On the other hand, evidence shows that the U.S. does not have overall superiority in military system technology. Without considering scenario, tactics, quantity, training or other operational factors, the U.S. DoD judges that parity between the two superpowers exists in many fields, including intercontinental ballistic missiles (ICBMs) and land forces. In some strategic weapon systems like ballistic missile defense, antisatellite weapons and surface-to-air missiles, the USSR appears to excel. In tactical air and naval forces and in command, control, communications and intelligence (C3I), the U.S. has the upper hand. As a whole, however, the U.S. lead is again eroding.[17]

3.2. Management of Military Technology Programs

Plausible explanation for the above "facts" is far from easy. But there are some clues. On the Soviet side, concentration of priority, exploitation of the "follower's advantage," ingenuity in offsetting the weakness of an inferior economy, determined military and political leadership, and intense development of military science and engineering are generally argued to be the major reasons.[18]

More specifically, the USSR has coped with the increasing "basic science content" in the weapon systems by close ties between the military industry and the Academy of Sciences. Well-known military-related research units under the roof of the Academy include the Institutes of Atomic Energy, Radio Engineering, and Precision Mechanics and Computing Technology clustering around the Department of Engineering Sciences, which in the early 1960s was abolished and whose original functions were partly redistributed among industrial ministries and partly taken over by the Department of Mechanics and Control Processes. The funding for military R&D is prioritized, flexible and project-oriented rather than rigid budgeting. And many Academy researchers serve military-industrial customers as consultants.

In the military-related industries, a number of ministries have their own capable R&D labs. For example, the Ministry of Aviation Industry maintains six principal R&D institutes for aerodynamics, engines, materials, equipments, production technology and flight performance respectively. The ministry and institutes, though responsible for standard-setting and thus inevitably inclined toward conservative uniformity, also consistently encourage and conduct frontier R&D and are famous for their role as an innovator, not conservative.[19]

In the uniformed military, in the post-Stalin era the General Staff has been in the center of weapon system development, integration, procurement and deployment, in addition to its normal military forces planning and development. Therefore the centralized military application of technology has been institutionalized for several decades.[20]

A similar strategy of centralization and systematization is also reflected in the Military-Industrial Commission (VPK) under the USSR Council of Ministers to coordinate defense industries and oversee the acquisition and application of foreign technology.[21] This strong, centralized command system may to a considerable degree explain the Soviet shorter cycle than the U.S. in utilizing novel technologies and deploying new systems. It is estimated that the time it takes the U.S. to deploy a single generation of military systems allows the USSR one and a half generations.[22]

On the U.S. side, despite its stronger capabilities in creating new technologies, its narrowing lead especially at the system technology level is attributed mainly to the political and bureaucratic constraints on long-range planning and technology project management, and the increasing complexity of regulatory regimes affecting military-related R&D in industry and universities.[23]

More specifically, funding in the U.S. is found particularly vulnerable in procurement or later stages of development. Funding also fluctuates widely from year to year because of Congress budgetary process, and this is very disruptive to long-term planning.[24] In competing for key technical and managerial personnel, the DoD's ability is declining.[25]

In technology development, three Services run, as a long tradition, their technology programs and R&D institutes differently. The Army emphasizes decentralization and owns many relatively small labs; the Navy stresses in-house R&D from basic research through pre-production stages and has larger and integrated labs; and the Air Force contracts out more of its R&D than the other two Services. In addition, there are the Defense Advanced Research Projects Agency (DARPA, formerly ARPA) taking care of technology that does not fit neatly into what the Services want to do, and the newly formed Strategic Defense Initiative Organization (SDIO) for the Strategic Defense Initiative (SDI). Basically, the whole planning is dominated by bottom-up approach: most real decisions are made within the component organizations. The Office of the Secretary of Defense only provides general guidance and reviews Service programs without exercising any strong role in molding them. In other words, DoD does not have a central headquarter-level system for planning and coordination, except for some special cross-Service programs, such as VHSIC, MMIC, SEI, STARS,[26] and the recent SDI. Though this system is not necessarily bad in the light of the professional knowledge needed to manage individual programs, it nevertheless lacks top level strategic planning and coherent and consistent program coordination.[27]

3.3. Design Strategies and New Technology Challenges

It should be noted, however, that it is a tradition in the Soviet weapon designs to stress simplicity, commonality, heredity and economy in response to its uneven and inferior technological base, constraints in production capabilities, and limited access to imported equipments and materials.[28] One example is fighter's engine. The Soviet engine for MIG-21 contains about one-tenth as many parts as the engine used in F-4, its U.S. equivalent of the day. Generally speaking, U.S. equipments tend to be more complex, and therefore tend to get built more slowly once production starts. Much more time is also required to get the "bugs" out of new systems and to train the crews to be proficient in their use. This reflects a technological emphasis on higher performance at the expense of

other factors such as cost and maintainability, and an emphasis on design technology over production technology, resulting in more costly systems. But once the bugs are out, many recent U.S. systems have proven more reliable, available, maintainable and operable.[29]

In recent years, many newly emerging technologies seem to impose more constraints upon the USSR than upon the U.S. in military technology development. In the earlier decades, most military (and even civilian) technological innovations were mainly based on known principles and proven applied science and engineering knowledge.[30] Military mechanization, aviation, early electronics, nuclear weapons and strategic delivery systems are all good examples, in which the USSR has shown distinguished records in mastering and catching up. But in many modern technological fields, where increasingly more basic scientific discoveries are directly connected,[31] broader array of disciplines and higher precision components, materials and equipments are needed,[32] and civilian industries are moving to the cutting edge of "dual technology,"[33] the Soviet overall weaker and "dual" development base and pattern have manifested severe problems. A good example is the Soviet significant lag in modern avionics and C3I behind the U.S. and some Western countries.

3.4. Similarities in Space Technology

In fact, the development pattern of stable, long-term commitment and strong, centralized management is also used in Soviet space programs. Its earth's first artificial satellite Sputnik 1 launched in 1957 is legendary. Its first real success in the study of Venus after 17 failing attempts shows its very tenacity and perseverance. It succeeded in 1986 studying Halley's Comet. And it recently re-embarked on the study of Mars. Now it has at its disposal a technology sufficiently advanced for implementing effectively most practical space applications. But the fact that the Soviet technological and industrial base remains relatively narrow is also reflected in its space programs. Although the Soviet spacecraft relies heavily on automated control with cosmonauts as backup, crewmembers have, in many instances, assumed broader duties than

their U.S. counterparts to make up for failures in automation.[34] Space technological applications in meteorology, telecommunications, navigation, reconnaissance, eavesdropping, remote sensing of the earth resources, etc. have all been developed, but with unsophisticated satellites which are heavy and unreliable, and have poor performance and a short life span relative to advanced Western satellites. Films of the civilian earth observation are still brought back on board retrievable capsules, whereas the U.S. Landsat or the French SPOT satellites for years have been transmitting accurate pictures. This relative technological weakness may explain why the Soviet space activities are far ahead of the rest of the world in terms of quantity: over 600 tons of payload put into near-earth orbit each year, a number three to four times that of the U.S.[35]

The "Soviet-type" development strategy in military and space technology programs is also used in Communist China. Despite its very backward civilian technology and industry, Communist China is "unexpectedly" strong in strategic nuclear weapons.[36] It also has satellites, launch vehicles and ground support facilities of its own development and production.[37] But it shows "structural shortcomings" similar to the USSR.

4. Nuclear Power Technology

4.1. Progress in Nuclear Power and Related Technology

In civilian technology, nuclear power in the USSR deserves special attention because of its nearly total self-dependence in this highly complex technology and its unique development pattern and consequence. With the exception of GDR and Czechoslovakia, none of the East European countries have any significant nuclear science experience or industrial capacity to start their own nuclear energy programs. Even GDR and Czechoslovakia, the latter failing in developing its HWGCR (heavy water-moderated, carbon dioxide gas-cooled reactor), have been fully based on reactors supplied from the USSR like the other East European countries. Therefore the following discussion is solely about the Soviet case.[38]

Like the U.S., the fundamental technology of Soviet nuclear power was first developed and tested for military purposes, and later transferred to the civilian industry. In nuclear physics, the USSR started a number of scientific institutes in the mid-1930s. In 1937 it built the Europe's first small cyclotron. In 1939 the spontaneous fission of uranium 235 was simultaneously discovered in the USSR. During World War Two, a large-scale "uranium program" was started in the military. In 1949 the first Soviet atomic bomb was exploded. In 1953 the first Soviet H-bomb was tested, only ten months later than the U.S.'s.

Due to the economic reason which includes heavy industrial energy consumption, shortening fossil energy supply, and costly remote sources exploitation, the Soviet energy policy in the post-war era was oriented mainly to nuclear energy.[39] Its world's first experimental nuclear power station (5 MWe) was put in operation in 1954. On a real industrial scale, LWGRs (light water-cooled, graphite-moderated reactors or, in Russian abbreviation, RBMK) (100 MWe each) and PWRs (pressurized water reactors or, in Russian abbreviation, VVER) (210 MWe each) were put into commercial operation in 1958 and 1964 respectively. In 1988, in the USSR 58 reactors in total were in operation, 27 units under construction and 45 units under planning, showing its strong determination to "go nuclear."[40]

In addition to the nuclear fission reactors, the USSR also gives the fusion research and fast breeder reactors (FBRs) top priority. In 1968 it developed the world's first tokamak, the magnetic confinement for fusion. Presently in the USSR two FBRs (135 MWe and 550 MWe) are in operation, a third one (750 MWe) under construction and a fourth one (1500 MWe) under planning. In the West, only France, whose government has been more successfully silencing public concerns about nuclear power, has two liquid metal fast breeder reactors (LMFBRs) (250 MWe and 1200 MWe). FRG's construction project started in 1974 but its completion has been postponed year after year and not yet finished. Except France and FRG, no other industrialized countries have serious FBR programs.

4.2. Management of Nuclear Power Technology and Consequence

The Soviet nuclear power technology in terms of progress in output scale and new reactor R&D is remarkable. This record can again be attributed to the state leadership and determination in stable, long-term investment. In reality, the state plan is like law. The designers, suppliers, operators and inspectors are all state employees. Completion of projects in time for some prescribed dates is rewarded. However, much of the information is classified. There has been little open challenge or criticism, even from East European countries. This is in striking contrast with the situation in the West, where public opinions and mass media "interrupt" construction and operation, independent regulatory agencies force utilities to defend the plant safety, and equipment suppliers and designers compete for market. But the result of the Soviet-type development is by no means satisfactory.

First, the Soviet nuclear power station per installed MWe effect is larger in size and usage of construction materials, and considerably higher in the number of operation and service personnel than the comparable stations in France and FRG.[41]

Second, safety is very problematic, clearly reflected in, for instance, the two stations exported to Finland in the mid-1970s. They were found unsatisfactory by Western standards and thus needed the U.S. firm Westinghouse's additional work in containment and reserve cooling systems.[42]

Third, the Soviet weakness in modern computers, microelectronics and automation, which are essential to the control of nuclear power, results in questionable reliability, safety and productivity, and serious shortage of simulators[43] which help train personnel and upgrade decision making quality.

The disastrous Chernobyl accident in 1986 has brought about far-reaching implications to Soviet development strategy, including reactor design and management. After the accident the USSR rather openly published highly sensitive information and invited many Western experts to investigate and provide advices. It is judged that Chernobyl-type reactors would have never got license in the West.[44]

Despite the Soviet official report that the main cause is human negligence, by Western standards the flaws in safety design are evaluated to have put excessive demands on plant operators.[45]

Though large public discussion or protests either in the USSR or in any East European country has not been evoked, the State Committee of the USSR to supervise safety related conduct, including training and construction quality, was created. The USSR Council of Ministers also made many concrete, not abstract, recommendations, prohibitions and responsibility assignments. And the reshuffle of leading figures was underway. In the meantime, a number of construction projects of LWGR (RBMK) have been suspended, and there has been a clear shift from LWGR to PWR (VVER), because LWGR is Chernobyl-type.[46]

The Soviet experience as mentioned above shows that much of the technical progress in nuclear power, especially in light of the military origin and technological complexity, can be enhanced by state strong leadership and long-term commitment. But on the other hand there exist many serious pitfalls. Lack of competition by suppliers may lead to complacency in cost-effectiveness. Politicized implementation may produce compromises in quality. Absence of independent regulatory checks and enforcement may sacrifice safety. Given that governments in most Western industrialized countries play a very influential and even direct role in nuclear power technology, the seemingly extreme case in the USSR may, on second thoughts, seem not so extreme. Many Western countries may in reality more or less share some similarities with the USSR. It is only a matter of degree. Others, due to weak state endorsement, entirely lack the indigenous capabilities in nuclear power technology.

5. Computer Technology

5.1. Early Development and Joint Program of Computer Technology

While there was no doubt about the necessity of nuclear energy, cybernetics (including early computer science) in the USSR was retarded by negative ideological attitude in the early years. It

was denounced as a mechanical system-oriented "pseudo-science" reducing the workers to an unthinking being. Even in 1962 the Soviet government made a decision to close down the computer division in the Academy of Sciences. Hence computer science was developed, if at all, under cover names and on a small scale. And computer technology and production were mainly the preserve of the ministries. Only in 1983 did the Academy take the first step to remedy and create a new Department of Informatics, Computer Technology and Automation.

Owing to the low quality and small number of hardwares and softwares, and their incompatibility provided by different countries, mainly the USSR, most countries in the Soviet bloc were oriented toward the Western computers throughout the whole 1960s. This embarrassing situation resulted at the beginning of the 1970s in a CMEA agreement upon the Unified System of Electronic Computers (USEC) derived from IBM models for the production of RYAD (or, in Russian abbreviation, ESEVM) series. There were six countries--the USSR, GDR, Czechoslovakia, Poland, Hungary and Bulgaria--joining this program. In accordance with signatory countries' level of technical expertise and production potential, each member focused on some special models except the USSR which covered the whole spectrum of computers. For attachments and related equipments, GDR was responsible for magnetic tape data storage equipments, Czechoslovakia for tapes, punch card machines and consoles for graphic registers, Poland for print-out equipments, Hungary for input-output equipments including visual-display units, Bulgaria for some other peripherals and components, and the USSR again was involved in all kinds of production. In 1974 RYAD 1 modeled after IBM 360 and 370 series came into existence, about 9 years after IBM machines were first introduced in the Western markets.[47]

About this program, no consensual evaluation could be found. For the USSR, this program definitely has been a valuable means of rushing its bloc's resources into this strategic but severely lagging field. Therefore, this project is often cited as an example of fruitful fraternal cooperation in the CMEA by the USSR. Comments from other participant countries are ambivalent, ranging from praise to

complaint.[48] A decade later, RYAD series computers were still in serious short supply. Software support was poor, reliability low, compatibility questionable, and installation and after-service slow. Until recently, there are no supercomputers in the civilian sector in the Soviet bloc. But it is believed that the situation in the Soviet military, space and nuclear energy departments is much better. Most central computers being used are obsolescent, usually 15-25 years old. This leads to a strong reorientation toward personal computers in the 1980s. Ironically, while struggling to catch up the West in large and medium size computers, the East again missed the tide of personal computers, resulting in its perhaps larger lag behind the West in personal computers than in large and medium computers. Now only small quantity of personal computers are produced using many imported Western components. In the meantime many kinds of imported IBM clone computers could be found but at very high prices. As a whole, the density of personal computer usage is very low, and very few personal computers, terminals and word-processing facilities are available. Even the supply of diskettes, ribbons, computer paper, etc. has serious problems. And it is said that the situation in the USSR is worse than in some other CMEA countries like Czechoslovakia, Bulgaria and GDR.[49]

5.2. Diverse National Strategies in Computers and Outcomes

GDR and Bulgaria are the two most enthusiastic East European countries embracing RYAD program. They have done heavy investment and developed their computer industries of some potential. In medium capacity mainframes and minicomputers, GDR's VEB Kombinat Robotron, a computer and telecommunications conglomerate consisting of 21 enterprises, is generally acknowledged to be the CMEA's leader. GDR was the first in the CMEA to start the production of RYAD 1 models. Within the CMEA GDR's major linkages are with the USSR, both almost totally relying on components manufactured by CMEA members. But because of the bad quality of other countries' supplies, GDR later had to relied more on its own production. GDR's products and technology are highly appreciated by

the USSR which accounts for the lion's share of GDR's computer export market. In strategy, GDR is "uniformly imitative" in nearly every key aspect: microprocessors, computers and system softwares. Western products modeled include Intel 8008, Zilog Z-80, IBM 360, 370 and 3300 series, DEC VAX 11/7XX series, and Microsoft MS-DOS. GDR could produce 16-bit microprocessors and demonstrated in 1988 1-Mb DRAM (dynamic random access memory) chips. But its computers were all introduced 6-7 years later than the copied Western models. Nonetheless it has undoubtedly established a credible technological and productive base of its own, though presently not competitive in the Western markets. But in micro- or personal computers, GDR has overlooked their potential and not supported Robotron's manufacturing effort in time. Technologically, GDR lags by more than one generation behind the Western front runners. In production, its base is small, estimated at 60,000 computers in 1988. The scarcity of personal computers so far also precludes the rise of "computer culture" in this country.[50]

As virtually the least developed country in the early CMEA organization chiefly based on agriculture in the early post-war era, Bulgaria's development for the past few decades has been relatively successful within the group.[51] But the stagnation in recent years has triggered a movement of decentralization and self-management, so-called "preustroystvo," the Bulgarian version of "perestroika."[52] For regaining national independence from the Ottoman Empire through Russians' help, Bulgaria has the most pro-USSR attitude among the East European countries. In its post-war industrialization Bulgaria has also benefited significantly from being closely affiliated with the CMEA in general and the USSR in particular. It has received much generous assistance from the USSR. Within the framework of CMEA cooperation and specialization,[53] Bulgaria was assured the CMEA market to establish its new industrial base with economies of scale, like the production of fork-lift trucks, electric telphers and electric vehicles. But its computer industry had not been existent until the mid-1960s. Through its specialization in electronics and firm commitment to small computers and some peripherals like disk drives, Bulgaria has put itself in a better position in computer

development than even the more industrialized Czechoslovakia. In strategy Bulgaria is also outright imitative. Unlike GDR, it seeks cooperation with the West. It produced Motorola microchips, worked with Hitachi and Toshiba in computers, and set up a center for Japanese specialists to train local technicians in robotics and other electronics.[54] But its computers are regarded as unreliable,[55] and disk drives as low quality.[56] Production management and quality control still stay at a rather primitive level by Western standards.[57] However, the large capacity investment with major machines and instruments mostly imported from the West in two state companies, Pravetz and DZU, manifests Bulgaria's ambition and possible potential. But the often shortage of some peripherals, attachments and repair parts usually could not be quickly corrected by domestic or other CMEA members' production or Western imports.[58]

As one of Europe's industrial and technological leaders, Czechoslovakia is still rather strong in traditional engineering industry, for instance, heavy machinery and diesel engines. But its electronization and computers are a big failure despite its originally substantial capacity in precision, electronics and computer related engineering.[59] Nowadays most of its machines have to incorporate Western numerical control parts, notably Siemens', in order to compete in the world markets.[60] The only production of personal computers is a small assembly factory mostly using imported components for 8-16 bit computers with 1-2 floppy disk drives and a hard disk up to 20Mb, and RAM memory of 256Kb-1Mb. This factory, however, is owned by JZD Agrokobinat Slusovice, an agro-industrial cooperative which, with rather highly managerial autonomy, is operated in a more or less capitalist way and praised by Gorbachev as an ideal model in East bloc. But it sells computers on a condition that about half of the price should be paid in hard currency, making it very difficult for local private users and even schools and other organizations to purchase.[61] Ironically, no state enterprises have any presence in personal computer production, in spite of the fact that in November 1987 a scientific-production union Microelectronika was set up with 45 members to coordinate microcomputer production, cooperation with foreign firms,

unification, standardization, compatibility, component imports, applications in industry, education, etc. In short, the poor situation of computer industry in Czechoslovakia can be attributed to at least two reasons. One is its rigid centrally planned system failing in responding to microelectronics challenge.[62] Another is its middle path of half-hearted effort in CMEA's RYAD program and hopeful glances toward Western technology which unfortunately has long been under embargo. It turned out that the latter "dual policy" locked Czechoslovakia out of both Western and Eastern markets because of the low quality unacceptable to the West and the weak production base for the East.[63]

Like Czechoslovakia, Poland also suffers from its "dual policy" in computer development.[64] Its situation has been further exacerbated by the decision to specialize in heavy industry, such as ship-building and steel, in the CMEA in the mid-1970s without paying and shifting attention to new microelectronics.[65]

The computer development in Hungary presents quite a unique picture.[66] Farther than other CMEA members, Hungary mainly relies on Western components.[67] Its participation in joint CMEA effort is rather perfunctory, resulting in early hardwares and softwares incompatible with CMEA's RYAD systems.[68] Around 1970, Hungary's computer industry was one of the region's most underdeveloped. In the late 1980s it is CMEA's largest producer of IBM-compatible personal computers, and provides regularly smallest model of RYAD systems in conformity with CMEA's specifications. It also exports computer products and services, most notably software, to Western markets. Unlike all the other CMEA members, Hungary with its most market-oriented system in the CMEA has a dynamic and rapidly growing entrepreneurial computer industry, consisting of hundreds of private cooperative firms,[69] many of which contract work to "moonlighting" individuals and small groups who work after regular hours. Hungary has a large installed base of computers owned by private individuals: more than 150,000 computers at the end of 1986, a number dwarfing the mere 39,000 machines owned by official organizations.[70] The diffusion of personal computers and abundant supply of computer books and software disks have created

a "computer culture" in Hungary much farther than in other CMEA countries. Despite its weakness in larger computers and components industry, Hungary's unique orientation toward Western technology and markets and entrepreneurial private sector help it at least hold a niche in the modern computer world.

As to the USSR, little information about computers in military and space programs is available for this research. In non-military areas, the computer technology and production are evaluated as very backward relative to the West and even as a crisis. The USSR has imported a large amount of GDR's mainframes and minicomputers to equip its key government departments and R&D institutes, and there has been widespread complaint from other CMEA users about Soviet products. In personal computers, the production of 8-bit Mikrosha was not started until 1987.[71]

6. International Cooperation within CMEA Framework

6.1. Limits to Fraternal and Gratuitous Cooperation

Without paying much attention to the historical locus of organizational arrangements to tackle intra-CMEA S&T cooperation,[72] the following discussion would only focus on the main features and trends which could be seen as a "mirror" to the Western pattern.

By standard process, international S&T cooperation within the CMEA framework consists of at least four levels of concerted effort: coordination of the five-year and annual plans at the national state planning commission level, cooperation of national branch ministries arranged by the standing CMEA Commissions, coordination of S&T activities by a special subcommittee of the Executive Committee, and bilateral and multilateral agreements and payment settlements.[73] Because each country always tries to insulate domestic affairs from external relations, without explicit permission of the respective central authorities, lateral communication across national boundaries is difficult. The CMEA S&T collaboration is thus characterized by lengthy and cumbersome national and international bureaucratic direction.

Historically, formal S&T cooperation in the East bloc was propounded during the first working year of the CMEA in 1949, starting with the so-called "Sofia Principle" which was a practical expression of the injunction of communism: "from each according to his ability to each according to his need," and called for fraternal and gratuitous cooperation and assistance. Under this protocol, only marginal cost of exchanging pertinent information and delegating on a temporary basis scientists and technicians to other member countries would be charged. This principle was intended to reduce the disparities among members, but the recipients obligated themselves to utilize the knowledge gained solely for their domestic development and not to undercut the donors' national and foreign markets. Due to the concern over reciprocity parity and amortization of R&D investment, more developed members were lukewarm about this collaboration pattern. So it was chiefly pushed by the USSR, and benefited especially less developed members.[74]

As a matter of fact, this principle virtually eliminates the market for technology and has several disadvantages. First, the donors may withhold up-to-date knowledge and have no incentives to assist the recipients in exploiting the knowledge transferred. Second, the recipients may thus lack pressure to do their own R&D. Third, knowledge exchanged may be less economically relevant, hence misguiding the recipients' direction of effort. Fourth, lack of appropriability may discourage the donors to innovate. Finally, the rule of market restriction imposed on the recipients is difficult to police.[75]

As time elapsed, the Sofia Principle was gradually replaced by ad hoc forms of compensation in practice. In recognition of the drawbacks of this principle and the growing unwillingness on the part of some members to engage in gratuitous exchange, the CMEA Executive Committee in 1970 formally called for the collaborative arrangements to consider the interests of every individual country, and to effect technology transfer under conditions similar to those prevailing in world markets, without excluding the generous assistance to the least developed countries.

6.2. Limits to Institutions without Market Mechanisms

But such "normalization" was seriously constrained by the insufficiency of methods of pricing and means of payment. In a traditional centrally planned economy, inventions and S&T knowledge are treated as state property available to be exploited by state enterprises without any particular payment. There is no tradition of pricing these intangibles. Moreover, the complex international payment settlement further complicates the transaction of these intangibles. In this regard, a joint R&D project in the CMEA context can provide a good illustration.

To calculate the contribution share, the input capital is disaggregated into construction, labor and tradables, each of which is evaluated in local prices and then translated into a common currency unit, usually the transferable ruble (TR), according to ad hoc exchange rates used for certain types of CMEA transactions. For labor cost, normally special exchange rates are as a rule utilized. But similar approach is more difficult to use for pooling know-hows, sharing resultant intellectual property, and estimating commercial value. Therefore to harmonize the interests of various members in joint endeavors is a very complex task. And multilateral arrangements are far more formidable than bilateral ones.

In recognition of the necessity of radical reconstruction of the CMEA cooperation, the Comprehensive Programs of Scientific and Technological Progress of the CMEA Member Countries to the Year 2000 (hereafter called CPST) was adopted at the 41st CMEA Session in 1985. CPST calls on CMEA members to concentrate their efforts and cooperate in five areas--electronics, automation, nuclear energy, new materials and biotechnology, and hopes for doubling factor productivity over the next fifteen years. Like several previous CMEA initiatives, tens, hundreds and thousands of different levels of projects, topics and themes were proposed, and hundreds of institutes involved. CPST this time, however, emphasizes four features which are totally novel: encouragement of autonomous initiatives and direct relations at the enterprise level, reliance to a greater degree on market mechanisms, facilitation of bottom-up communication, and utilization of international institutions and

mechanisms to buttress concerted effort in key areas.[76] But this new strategy apparently cannot fit into the old context, national and international, and most old systemic barriers to innovation persist. Without fundamentally restructuring the centrally planned system, the prospect for CPST is dismal. Therefore it is not surprising that, up to now, too much of the collaboration remains on paper, and most member countries only pay lip service without real enthusiasm.[77]

To make matters worse, there is a long history of wide resentment among the Soviet allies that the USSR has tapped East European S&T expertise and resources to its own needs.[78] One evidence is that most key collaborative R&D centers are located in the USSR, absorbing disproportionately good equipments and people toward the USSR.[79] Another evidence is that quite a number of joint projects are biased toward solving problems which are most relevant to the Soviet domestic needs.[80] Therefore there is resistance, latent and manifest, from Soviet allies against the S&T integration centering around the USSR.

The preceding analysis of CMEA cooperation suggests that there are no easy solutions to CMEA's innovation crisis. Its causes are so endemic to the national and international politico-economic systems. The current trend seems to downplay the cooperation within the CMEA framework, and the centrifugal forces in this bloc are leading the reforms oriented to the West. This implies that the intra-Eastern cooperation based on the traditional framework will diminish.

7. Managerial Implications

7.1. Uneven Performance in Three Technological Fields

The preceding discussion reveals three very different pictures respectively about military, nuclear power and computer technologies in the East. Relative to the West (and, in military field, mainly the U.S.), the East (mainly the USSR) has performed well in military technology, especially system technology. In nuclear power technology, the East (mainly the USSR) has also performed well in technical terms but at the great expense of safety terms. In computer technology, the overall records of the East are quite poor.

Because these three technologies are all of utmost importance to the USSR or all CMEA countries and under party-state strong support and direction, their strikingly uneven performance may largely be attributed to some systemic causes relating to how the national institutions tackle technology development.

Concerning the national institutions, the East is characterized by centrally planned and directed systems. Its civilian sector's capabilities in technological innovation are very weak relative to its military counterpart's. Besides, its public sector is overwhelmingly dominant in most countries.

As regards technology, the degree of its dynamic nature appears to be of most relevance to the present discussion. In military technology, the Soviet different performance in system technology and basic technology relative to the U.S. also deserves some elaboration.

By comparing the interactions between the Eastern national institutions and technologies of different characters, many relevant and timely implications for managing technology may emerge.

7.2. Centrally Planned System for Various Technologies

The CMEA's overall weakness in computer technology, including the Soviet significant gap with the U.S. in military applications (e.g., C3I) and with the West in nuclear power control and simulation, has its deep root in the basic assumption about technology progress inherent in its administrative and managerial approach.

In nuclear power (mainly fission) technology, the progress, after the initial breakthroughs and fundamental R&D had been done for military purposes, was basically incremental in some roughly predictable directions, or in the so-called "trajectory" phase.[81] Given its high technological and system engineering complexity, long-term commitment and large-scale investment according to some prescribed, perhaps rather rigid, plans could work to the extent that they are well organized and no critical parameters and aspects are neglected. The Soviet experience has dramatically proven both sides: excellent technical performance records, which were under state

intense direction, and bad safety designs, which were not prioritized and thus largely neglected.

By contrast, modern computer technology or, a broader field, IT represents a "paradigm" change which is based on a combination of radical product, process and organizational innovations.[82] To exploit its potential, it also requires changes in the structural and institutional framework. In other words, the relative success of a society rests on the degree of match between the emerging new paradigm and the adjustment of institutional framework. In view of the CMEA's general backwardness, it seems to assert that the centrally planned system, characterized by vertical channels of communication, mainly top-down direction, not coupled by lateral linkages and autonomous initiatives from bottom up, is not in compatibility with the new IT paradigm. But this does not mean that the centrally planned system cannot work at all. In imitating IBM computers which were in "trajectory" phase in the 1970s, the determination and heavy investment by GDR and, most notably, the less developed Bulgaria have without doubt produced some results even if not comparable to the performance of Japanese firms also imitating IBM computers. But in personal computers which were not on the stage until the late 1970s and since then expanded enormously, the whole CMEA, with a few exceptions like the Hungarian private sector and a Czechoslovak cooperative, missed the express train. It is not because personal computers demand more advanced and sophisticated technological capabilities than larger computers do. It is because there is little entrepreneurial spirit and mechanism in the East to grasp this dynamic opportunity.

Besides electronics and nuclear power, in fact, new biotechnology, new materials and automation are the other three areas identified by the CMEA for extra and novel systemic efforts in joint program CPST. Even if it may be questionable for the term "paradigm change" to be used for new biotechnology and new materials, both as well as automation (which could be included in the broad IT field) show very dynamic character quite different from "trajectory" technology.

In automation, most CMEA countries have had long experience in traditional engineering industry. But in novel robotics, most lag very much behind the West. They have large capacity of car industry, but, unlike in Western countries, their car industry has not become a successful nurturing ground for modern automation and robot technology. Lack of modern microelectronics is one reason. Lack of competition pressure to innovate is another.[83]

In traditional biotechnology, the CMEA has also had long history. But in "new biotechnology," which was triggered by genetic engineering in the mid-1970s, there has been no sign of new products introduced by CMEA countries. Despite the scientific community's recognition of the importance of new biotechnology and its rather forefront fundamental research, the industrial activities are inactive. The prevailing lack of incentives to commercialize the scientific findings is pointed out as the main reason.[84] This is also in contrast with the West where many small innovative enterprises and established large firms are active in capitalizing on the new opportunities.

In "new materials," except structural composites for military purposes, the CMEA also trails the West. Most research remains at the stage of understanding basic properties and structure of materials. The shortage of high precision and sophisticated facilities to support applied R&D and industrial production is the direct cause, behind which is the rigid bureaucracies that could not respond fast enough to the new challenge.[85]

Although basic science and fundamental research is beyond the scope of this research, the fact that, the USSR and most East European countries are strong particularly in mathematics and theoretical physics as well as fields requiring large single facilities such as observatories or accelerators, but weak in the fields which need a multitude of smaller, sophisticated instruments or ultra-pure, custom-designed materials and reagents, such as chemistry, electronics, biological and medical sciences,[86] could to some degree be explained by the foregoing same arguments. That is, the Eastern system may be successful in dealing with "centralized" issues with

rather clear direction of effort, but it is very weak in handling topics of dynamic and "decentralized" character.

As a matter of fact, the Eastern national pattern of tackling technologies is also reflected at the CMEA multinational level, resulting in a very different picture from the Western one. In the West, many initiatives come from "action organizations" and are supported by governments and international bodies like the European Economic Community with at most broad guidelines and reviews. In the East, cumbersome bureaucratic systems at both national and CMEA levels suffocate most initiatives, be they top-down or bottom-up, let alone the adverse impact on technology transfer and joint R&D caused by "artificial" systems of pricing and international payment settlement.

7.3. "Dual Structure" and "Spin-off" and "Spin-on"

"Dual structure" in the Soviet bloc has inhibited many civilian technology progress. As a matter of fact, it may also retard military technology development.

As the U.S. experience shows, many modern high technologies, including computers and semiconductors, originated from military (and, to a lesser degree, space) mission-oriented R&D. They then were followed by the so-called "spin-off" phenomenon,[87] process of which could be briefly depicted as such. In the beginning, military procurements account for most of the production. But the strong and autonomous civilian industry competes for applying the early technological success for commercial profit. This expands markets and production, drives the cost down, improves the quality, extends the applications, upgrades the productivity, and even forms a new "industry." This in fact is a "virtuous circle," in turn supporting military (and space) missions. In the meantime the government mission departments and agencies continue to provide substantial endorsement for both basic research and high-risk, high-cost development projects that could have major impacts in the future. It is worth noting, however, that successful "spin-offs" are rarely planned in advance by the U.S. mission agencies. It is basically an unexpected phenomenon "joined" by civilian autonomous initiatives.

For the Soviet allies, it might be difficult to expect significant "spin-off" effects given their presumably much smaller military R&D expenditures relative to the U.S.'s. But as the USSR spent huge amount of resources, only matched by the U.S., in the military and space technology development, it is rather surprising that there has been no evidence of similar "spin-off" effects. Take modern IT as an example. In view of its obviously imitative strategy to take the follower's advantage, the USSR must have known the direction of technological effort for the relevant industry. Many of its advanced military and space systems suggest that it must have possessed some capabilities in advanced microelectronics, computers and telecommunications, regardless of their quantity, quality and actual cost (which is related to yield rate as in the case of semiconductors). But the USSR failed in creating a "viable" technological and industrial base comparable to the West. A plausible reason would be that a technologically capable and autonomous non-military sector in the USSR, or even in the whole CMEA, has been largely neglected by the party-state or stifled by the centrally directed system. As a result, this weak sector could not implement the "second phase" technology development succeeding the initial military (and space) R&D investment, as in the U.S., to accumulate much learning experience in diverse applications and markets, mass production, and incremental innovation, and then to in turn support the military requirements by abundant supply, lower cost and higher reliability. In other words, there has been no "virtuous circle" between military and civilian sectors. The former has to rely solely on itself in both technological and productive respects, and the latter could not benefit from the former's technological advancement.

The disadvantage stemming from the Soviet and CMEA's weak civilian sector is also evident even when compared with Japanese experience. Without any significant military presence relative to the U.S. and the USSR, let alone military R&D, but through the market pull of the enormous civilian applications, including its world number one consumer electronics production,[88] Japan has been successful in establishing its indigenous semiconductor and computer base. This base has become a cornerstone of all its IT products and even

military and aerospace systems. Now the U.S. military has shown deep concern over its dependence upon Japanese "dual use" microelectronics.[89] Using a convenient term as opposed to "spin-off," the Japanese pattern could be called "spin-on"--technology originating from civilian sector is utilized for military applications. The absence of a technologically strong civilian sector in the USSR and the CMEA thus also deprives them of any "spin-on" opportunity.

In all, albeit with some high-tech enclaves under state full direction and support, the country with "dual structure" will be very disadvantageous especially in face of potentially "dual use" technologies, because they tend to underutilize them.

Laser is another example illustrating similar pattern of discrepancy between the East and the West as noted above. The fact that two Soviet and one American scientists shared 1964 Nobel Prize indicates that the fundamental research in the USSR and in the U.S. achieved roughly the same level. Twenty years later the USSR and the U.S. are evaluated as roughly equal in military laser (i.e., high-power guided energy) technology, both mainly supported by the military.[90] The fundamental research of basic properties of various kinds of laser in the CMEA is also judged to be roughly equal to that in the West. But in the whole CMEA, the civilian applications are relatively primitive, and the civilian industry is just beginning, lagging far behind the West.[91]

7.4. Distinction in Managing System and Basic Technologies

The difference between system technology and basic technology has some managerial implications. Without much generalization, the following analysis is mainly confined to the military technology as precedingly discussed.

Military (and space) system technology starts with mission definition, feasibility analysis and system specifications taking into account of the availability of subsystem or "element" technologies. In practice, major system designs have to be based on some assumptions about the scientific and technological progress, and have to be "frozen" before more detailed tasks begin. This implies that normally the system level designs cannot incorporate subsystems

and elements of too much uncertainty or needing major breakthroughs that are very unpredictable. In other words, the subsystem and element technologies under consideration to support system designs are mostly "on the shelf" or in the rather predictable "trajectory" phase, and the major challenge to the system level efforts rests on the integration of "lower aggregate level (or element) technologies" to meet the criteria at the system level, such as effectiveness, reliability, maintainability, supportability, ergonomics and economic feasibility, and their trade-offs.

When unexpected major innovations take place at the element levels, they may significantly contribute to the higher aggregate system levels, or even change the system concepts. But their impact on the whole system may take some time because the innovations, if adopted, may create internal incompatibility or "system inequilibrium," hence necessitating the adaptations or advancements also in other parts of the system, which may take the form of product or process, in order to reach new "system equilibrium."

Conversely, innovative "ideas" at the system technology level, many of which are directly derived from mission requirements, may also guide innovative efforts at the element levels. To realize the system level innovations, however, there may be multiple alternatives: to mainly wait for the element technological innovations which would later be incorporated into the system, to mainly advance the system integration technology with or without major changes in the "portfolio" of element technologies that are already "on the shelf," or a combination of both. This fact points to the possibility of loose linkages between system technology innovation and element technology innovation. And basic technology, in relation to military and space mission systems, possesses the character of element technology.

As previously mentioned, with an overall inferior basic technology the USSR seems to have greatly narrowed the gap behind the U.S. in military system technology. Without getting into more details about various items, the Soviet relatively remarkable achievements at the system technology level may be attributed to its strategy and management system. In strategy, as noted above, the

USSR puts different emphases than the U.S. on system design parameters to compensate for its overall technological weakness, hence achieving system technology "more comparable" to the U.S.'s. In management, the Soviet more centralized commanding system, which by "common sense definition" may well mean stronger request in following prescribed routes, more pressure for collective actions, less rooms for autonomous initiatives at the lower levels, and more "mechanistic" (as opposed to "dynamic") organizational character, may lead to greater efficiency, all others being equal, in integrating "on-the-shelf" technologies for the given missions. What is more, the frequent time lag between the major basic technology innovation and the induced system technology innovation may also provide a chance for a follower in the basic technology to narrow the gap with the leader in the system technology. By estimating the potential impact of the innovative basic technology upon the system technology, the USSR can start working on novel systems, perhaps in parallel with the old ones, while in the meantime advancing its newly lagging basic technology by imitation or other acquisition means. Under the worst circumstances, the USSR can try to use new "portfolios" of existing elements to match the U.S. in system performance.

Despite its possible advantage in managing system technology, this command management pattern will lose much of its power in approaching basic technology, because basic technology is more directly connected to scientific discoveries and fundamental research, which require more freedom and autonomy.

8. Concluding Remarks

Recently Gorbachev, while downgrading the status of military commanders in several symbolic ways, has praised the military-industrial system and space and missile programs as a model for the rest of the Soviet industry to follow. In his reform, the basic practice of military-industrial establishments has not been altered. On the contrary, more military-industrial executives have been promoted than ever before and many military-related ministries have been requested to contribute to the modernization of civilian economy.

The close user-supplier relations between uniformed military and military-industrial establishments and the quality control system through "military representatives" are also modeled in the civilian industry.[92]

On the other side, the appointment of Marchuk as president of the USSR Academy of Sciences in 1986 and Tolstykh as chairman of the State Committee on Science and Technology (GKNT) in 1987 made clear the Soviet strong intention to heal its "Achilles' heel" in modern electronics. GKNT is mainly responsible for technology policy and foreign technology acquisition, and the Academy for fundamental science policy. Earlier heads of these two organizations usually had background in physics, thermodynamics, chemistry or mathematics. But Marchuk and Tolstykh both specialize in electronics: Marchuk doing computer basic and applied research and working with industry and the CMEA computer programs, and Tolstykh employed in aerospace, military and consumer electronics factories and as deputy minister of the electronics industry of the USSR.[93]

Besides the actions to apply the military and space management experience to vitalize the civilian sector, and to assign key leaders to strengthen modern electronics, there have been some other measures in the USSR attempted to remedy the "structural flaws." For example, hundreds of centers, associations and complexes keeping all stages of the R&D cycle under one umbrella have been set up, some operated by production ministries and others by the Academy of Sciences. A sharper difference of pay scale rewarding achievements rather than formal rank or seniority has been introduced in R&D organizations. Greater democracy in the Academy and delegation of more authority down to its 17 departments have been promoted. A system of financing research projects on a competitive basis, some by peer review, has been tried.[94]

In other CMEA countries, the present radical transitions moving away from the Soviet model make the attempt to reorient and consolidate new S&T development system not very appealing. The major effort in this field would come only after new and rather stable politico-economic institutional frameworks take shape. It is

now more urgent to concentrate on the latter arena, which in fact is the context and infrastructure for S&T development and innovation.

All the actual evolution in the USSR and other CMEA countries remains to be seen. Given the deep-rooted tradition and momentum, and many systematically determined causes which have been entangled together in a rather "internally coherent" way, it may take quite long time and require great wisdom and effort to realize the "perestroika" and "glasnost" of technology development and innovation in the East.

Notes

[1] It is commonly known that in the Soviet bloc much information publicly available has been manipulated to varying degrees by governments. Due to the political culture and control which make many people reluctant to freely express their true opinions and to release information not in conformity with official stands, it is also difficult to do behavioral and policy study in this bloc.

[2] A number of professional interpreters and local friends helped a lot in the field research. But the progress was still seriously constrained due to the inability to read and talk to people freely.

[3] For a historical review, see, for example, Parrott (1983).

[4] The combination of "North-South" and "East-West" nature of Communist China in technology transfer is briefly discussed in Chiang (1987).

[5] This is a general observation in most East European countries, the USSR and Communist China. For more details in the USSR, see Graham (1987).

[6] See Sagdeev (1988).

[7] This phenomenon is said to persist without much change until recently in the USSR. See Sagdeev (1988).

[8] For the weakness of the Soviet S&T administration, see, for example, Sagdeev (1988).

[9] For some exceptions, like Siberian Branch of the USSR Academy of Sciences, see Dickson (1988).

[10] For the Soviet system of financing institutes as compared with the U.S. system of financing projects, see Gustafson (1980), pp. 35-38.

[11] As an example, in 1982 only 3% of people with degree of "kandidat" (approximately equivalent to U.S. doctoral degree) worked in the Soviet

industry. By contrast, about 24% of all doctoral scientists and engineers were employed by industry in the U.S. in 1975. See Graham (1987), p. 5.

[12] For the physical setting of research institutes, see Gustafson (1980), pp. 48-54.

[13] See Stent (1989) and Winiecki (1987). It is due to the inability of the Soviet Bloc to harness Western technology as effectively as once believed that some in the West advocate for looser control of technology export to the Soviet Bloc. See Goldman (1984). For a similar situation in Communist China, see Simon (1990).

[14] This is measured by the relative prices of comparable engineering products. See Winiecki (1987), p. 117 and 142.

[15] For the discrepancy of policy making, program administration and real world R&D activities, see Main (1988).

[16] DeLauer (1984).

[17] For a more recent study of the situations in the U.S. and the USSR and the U.S. eroding position, see U.S. Department of Defense (1986).

[18] Gustafson (1988), pp. 1-3.

[19] Gustafson (1988), pp. 21-30.

[20] Currie (1984).

[21] Gustafson (1988), p. 57.

[22] This was testified by U.S. Secretary of Defense Caspar W. Weinberger. See U.S. Department of Defense (1983).

[23] For details, see Merrill (1985).

[24] For military technology funding issues, see U.S. OTA (1988), pp. 34-37.

[25] U.S. OTA (1989), p. 9.

[26] The abbreviations respectively refer to Very High Speed Integrated Circuits, Monolithic Microwave Integrated Circuits, Software Engineering Institute, and Software Technology for Adaptable, Reliable Systems.

[27] This is one of the main conclusions in a recent OTA report. See U.S. OTA (1989), pp. 12, 19-22 and 41-60.

[28] Brower (1982).

[29] U.S. OTA (1988), pp. 1-2.

[30] This is the main conclusion reached by the Project Hindsight, sponsored by U.S. Department of Defense to trace the contribution of basic science to weapon systems developed from the end of World War Two to the early 1960s.

[31] For the rise of "science-based technology," see Freeman (1982), pp. 1-104. But so far there has been no update research which can show in more rigorous terms the increasingly direct contribution of basic science to military technology since the 1960s.

[32] This is a general observation without support by rigorous study.

[33] The increasingly important role of civilian industries in modern military technology is discussed in more details in U.S. OTA (1988), pp. 15-17 and 42-46, and U.S. OTA (1989), pp. 161-187.

[34] U.S. OTA (1983), p. 4.

[35] Dupas (1987).

[36] For a brief discussion of Communist China's recent military technology development, see Chiang (1987).

[37] For a brief discussion of Communist China's space programs, see Liu and Min (1987).

[38] Except being specifically indicated, the information about the Soviet nuclear power technology development is mainly from Janouch (1988b).

[39] For the nuclear energy policy and cooperation in the CMEA, see Sobell (1984), pp. 35-72.

[40] Using x-y-z to represent the reactors in operation, under construction and under planning, the USSR is 58-27-45, the U.S. 110-11-0, FRG 23-2-0, the U.K. 40-3-3, Sweden 12-0-0, France 54-9-6, and Japan 38-12-16. This information is from the independent database of *Nuclear Engineering International.*

[41] This comparison was made in Czechoslovakia.

[42] This is based on the interview with the director of reactor lab in Technical Research Center of Finland in May 1989. See also Janouch (1988b).

[43] In 1988 the USSR had only two simulators. By contrast, the West has an average of one simulator per three to four reactors.

[44] This is judged by a former safety chief of U.S. Nuclear Regulatory Commission, who did field investigation of the Chernobyl accident. See Sweet (1989), p. 51.

[45] A number of reports about Chernobyl accident have been published by IAEA and several Western countries. For a brief discussion about the technical issues, see Sweet (1989).

[46] For more details about the Soviet post-Chernobyl actions, see Janouch (1988b).

[47] For early history and development of computers in the CMEA, see Janouch (1988a), Gustafson (1988), pp. 69-70, Sobell (1984), pp. 159-171, and Kassel (1986).

[48] See Judy (1988). But the Soviet allies' comments should be taken cautiously given the political situation.

[49] This is a general impression from the field visits and discussion in five East European countries in August 1988, and July, September, October and November 1989. There is no accurate information available. Similar field visit impression could be found in Janouch (1988a).

[50] For a brief discussion of the computer development in GDR, see, for example, Judy (1988).

[51] For a brief comparison of CMEA members' development records, see Marer (1989).

[52] For the recent restructuring in Bulgaria, see Doumayrou (1988).

[53] For CMEA cooperation and specialization, see, for example, Sobell (1984).

[54] Stent (1989), pp. 90-91.

[55] This opinion was expressed by most users met during field research in Bulgaria in June 1989.

[56] This is GDR Robotron's experience of using Bulgaria's disk drives.

[57] This is based on the observation of field visit to two most advanced factories in Bulgaria in June 1989. The factory producing personal computers has many problems in production management and quality control, and the other factory mainly producing disk drives seems better.

[58] This is a combination of some Western visitors' observation and local users' opinions during two visits to Bulgaria in July 1988 and June 1989.

[59] For the technology in Czechoslovakia, see Levcik and Skolka (1984).

[60] This is a main finding in a big machinery fair in Brno, Czechoslovakia in September 1989.

[61] This is based on a field visit and discussion in JZD Agrokobinat Slusovice in Gottwaldov in September 1989.

[62] This is based on the interviews with government officials and scholars in Prague in September 1989. See also Janouch (1988a).

[63] Clough (1988).

[64] Clough (1988).

65 This is based on the interviews with the director and staff of the research department in the State Central Planning Office in Warsaw in October 1989.

66 A brief review of the computer industry in Hungary with statistics translated from Hungarian language can be found in Judy (1988).

67 This is also a main finding from the interviews and field visit in Budapest in August 1988. It is said that the components produced by the East bloc are much less reliable and only used in products to be exported to other East bloc countries.

68 Davis and Goodman (1978).

69 A minimum of 15 members is required to form a cooperative in Hungary.

70 These numbers were published by the Hungarian Central Statistical Office in a study "Tasks, Conditions and Socioeconomic Interdependence of Data Processing and the Use of Information Technologies."

71 For a brief discussion about the Soviet computer technology, see Janouch (1988a).

72 For a brief historical review, see Sobell (1984), pp. 211-224.

73 Fallenbuch (1988).

74 For example, according to the interviews and field study in Bulgaria in May and June 1989, Bulgaria benefited greatly from Soviet gratuitous assistance in the post-war period.

75 Van Brabant (1988a).

76 Sinclair and Slater (1988).

77 For the unsatisfactory implementation of CPST, see Judy (1988). Similar opinions were expressed in several interviews with high-ranking government officials of the East bloc in Budapest in August 1988, in Prague in September and October 1989, and in the International Institute for Applied Systems Analysis (IIASA) in Vienna in 1989. This phenomenon was also asserted by some participants in a seminar in the USSR Academy of Sciences in Moscow in November 1989.

78 Judy (1988).

79 Van Brabant (1988b).

80 Many projects in biotechnology are good examples in this regard. See Rimmington (1988).

81 The "trajectory" vs. "paradigm change" in technological innovation is detailed in Dosi (1982).

[82] Freeman (1988).

[83] For automation and robot technology in the CMEA, see Hopwood (1988).

[84] For "new biotechnology" in the CMEA, see Rimmington (1988).

[85] For "new materials" in the CMEA, see Rentzepis (1988).

[86] For more details about the Soviet fundamental research and basic science, see Gustafson (1980).

[87] The U.S. experience in the development of computers and semiconductors is well documented. For government role in the early days, see, for example, Flamm (1988) for computers and Asher and Strom (1977) for semiconductors.

[88] For the connection between consumer electronics and semiconductors in Japan, see Vickery (1989).

[89] See U.S. OTA (1988), pp. 13-15.

[90] DeLauer (1984).

[91] For a comparison of laser research, civilian applications and industry between the East and the West, see Laude and Wautelet (1988).

[92] For the expansion of military-industrial establishments' influence and the application of their experience to civilian sector, see Gustafson (1988), pp. 80-98.

[93] For more details about Marchuk's and Tolstykh's background, see Graham (1987), pp. 12-18.

[94] For the Soviet recent reform in S&T development, see Graham (1987), pp. 24-38, and Sagdeev (1988).

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